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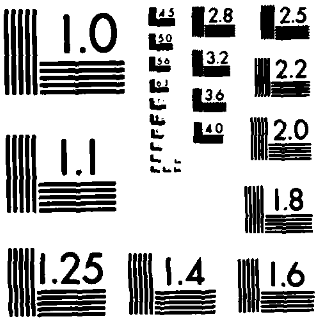
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GLOBAL POSITIONING SYSTEM - GEODETIC APPLICATIONS

by

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Introduction

The NAVSTAR Global Positioning System (GPS) is a joint service space-based radio navigation network of the U. S. Department of Defense with the Air Force as the executive service. The system, which will be fully operational in the late 1980's, has evolved from Air Force and Navy programs initiated in the mid-1960's. GPS will provide accurate time and three dimensional position and velocity information to users anywhere in the world, including those in near-earth orbits. The (real-time) navigation position determinations will be based on satellite-to-user transit times of modulated microwave signals broadcast by the GPS satellites. For navigation, the capability for absolute positioning on the order of 200 m or better will be made available for general civil use. (Reference is Federal Radio Navigation Plan dated June 1980.) The highest accuracy three dimensional navigation capability, on the order of 16 m, will be made available to U. S. Government agencies and to qualified U. S. commercial users where proper security measures can be established. Even higher accuracy relative geodetic positioning capability, on the order of 1 to 10 cm (depending on the baseline lengths), will be attainable by radio interferometric (differential phase) techniques which will be available for general civil use. Achieving these high geodetic accuracies requires continuous simultaneous observations for up to two or three hours at each survey site. Accurate relative (non real-time) navigation positions and velocities, using doppler and integrated doppler techniques, will also be feasible for general civil use.

Navigational Positioning Concept

GPS is comprised of three major segments: space, control and user. The space segment will consist of a constellation of at least 18 NAVSTAR satellites revolving about the earth every 12 hours in near circular orbits at altitudes of approximately 20,000 km. Three satellites will be equally spaced in each of six orbital planes. The inclination of each plane to the equator will be 55 degrees and their ascending nodes on the equator will be separated by 120 degrees. The satellites will be distributed so that an observer will have at least four of them sufficiently above the horizon at any time to be observed anywhere in the world.

Each NAVSTAR satellite carries an atomic clock with stability of the order of 1 part in 10^{13} to synchronize the broadcast navigation signals at two L-band frequencies: L_1 at 1575 MHz (19 cm wavelength) and L_2 at 1228 MHz (24 cm wavelength). Each carrier frequency is biphase modulated with pseudo-random noise (PRN) ranging codes and a navigation message uploaded from the control segment that contains clock correction and ephemeris information for all users, and additional information such as ionosphere propagation delay model coefficients for single frequency users. With an accurate clock, synchronized to GPS time, a user could measure the transit times from three satellites, multiply them by the speed of light to get their ranges and, knowing their positions from the navigation message, determine his position by trilateration. Most users will not have sufficiently accurate clocks (they will determine pseudoranges rather than ranges) so they will require the transit time from a fourth satellite for the simultaneous solution of position and time in the GPS frame.

Two PRN ranging codes may be used on orthogonal carriers at L_1. The L_2 may be commanded to have either P code, C/A code or none. C/A (course/acquisition) code is used for initial acquisition of the satellite signals and for coarse navigation; and the P (precise) code is used for accurate navigation. Each satellite has its unique C/A code that repeats its 1023 chip pattern every millisecond. The C/A codes are not classified and, if they were, they could be easily deciphered because the patterns repeat themselves continuously. Each C/A code chip is approximately 1 μsec long and the user's code generator can lock onto the code to roughly 100 nsec or 30 m in range. Because of the millisecond repetition period, there is a 300 km ambiguity in range that must be resolved by other techniques. Unlike the C/A code, the P code is not available to all users. Each satellite is assigned a seven day segment of a single P code that repeats its pattern of approximately 100 nsec length chips every 267 days. Because the resolution of the P code is ten times finer than that of the C/A code, it offers a significant (but less than tenfold) improvement in potential navigation accuracy over that of the C/A code. Moreover, because of the length of the P code, there is no ambiguity in a P code derived range measurement.

For Security Reasons, GPS accuracies will be degraded to all but authorized users. Furthermore, because of Congressional direction to investigate the concept of collecting user fees from non-DoD users of GPS, DoD policy may require that non-DoD users pay some cost for GPS services.

Geodetic Positioning Concepts

If the position of a fixed station is determined repeatedly using the standard GPS pseudorange approach (or by a Doppler solution using the L_1 and L_2 carriers), and a mean position is determined, random positioning errors will be driven down by redundancy. The limitation in the positioning accuracy would then be due to system (ephemeris included) biases, and an ultimate accuracy of no better than about one meter could be expected. As with other satellite surveying systems, the highest accuracy surveys with GPS can be attained by making relative (or differential) measurements between two positions. (Even with the degraded C/A signal, differential navigation offers the capability of guiding aircraft in precision landing approaches.)

The highest accuracy relative geodetic surveys use the L_1 and L_2 carrier phases as observables. Six degrees of L_1 carrier phase (about one tenth of a radian or six bits of information), which is easily resolved, is equivalent to about 3 mm in range. The differential carrier phase survey approach has been demonstrated by C. S. Draper Laboratory, using its MAE GPS receiver, and it will be used as one of the modes of the tri-agency (Defense Mapping Agency, U. S. Geological Survey, National Oceanic and Atmospheric Administration) geodetic receiver, the Geostar. At MIT (Massachusetts Institute of Technology) and JPL (Jet Propulsion Laboratory), GPS receivers have been designed and built for making differential carrier phase surveys. These receivers recover the L_1 and L_2 carriers without having to know the C/A or P codes and they will not require decryption devices to operate. Thus, users of these types of receivers will pay no user fees to the U. S. Government; however, they do not provide real-time navigational capability. Indeed, this approach can also be used with the Soviet space navigation system of which Cosmos 1413, 1414 and 1415 appear to be the first three satellites. A commercial version (single carrier) of the MIT receiver is now being marketed by Macrometrics, Inc., of Woburn, Massachusetts. The JPL receiver is being commercialized by ISTAC, Inc., of Pasadena, California.

For the rest of this talk, I shall discuss the progress of the MIT program in GPS. AFGL has supported the MIT program and is most familiar with it because of our day-to-day association with MIT and because of their ample publications. MIT has pioneered in the development of VLBI (Very Long Baseline Interferometry) for the measurement of intracontinental and intercontinental baselines by interferometric observations of quasars by radio telescopes. As long ago as 1969, MIT used VLBI observations of the TACSAT synchronous satellite to demonstrate the feasibility of using radio interferometry for accurate satellite tracking and for geodesy. With the advent of GPS, the extension of VLBI concepts for GPS surveying was obvious. The high signal to noise ratio signals from the NAVSTAR satellites replaced the weak quasar sources, so compact omnidirectional antennas were adequate to replace the massive steerable radio telescopes. In 1980, MIT set the compact MITES (Miniature Interferometric Terminal for Earth Surveying) antennas at the three vertices of a 280 m perimeter triangle at Haystack Observatory and collected the L_1 signals from five NAVSTAR satellites. The signals were converted to video bands and cross-correlated on the Haystack Mark III Correlator in real-time. In this process, the undecoded signals from the different satellites were discriminated through their different Doppler shifts and phase differences across the baselines. With 1.3 hours of observations on each of two days, the repeatability in the determination of each component of each baseline was better than 1 cm, and each triangle closed to within 1 cm.

In April of 1982, MIT measured the 1.1 km baseline between the Haystack and West Ford antennas using the Macrometer V-1000 terminal (identical to the MITES single frequency terminal) and GPS L_1 signals. With less than two hours of observation when five NAVSTAR satellites were observable, the baseline vector was determined to better than one part in 10^5. The data collected at each terminal, approximately equivalent to the amount of data that can be packed into one IBM binary punched card, were processed that same day by an LSI 11 microcomputer in approximately 30 minutes. In 1979, NGS (the National Geodetic Survey) had measured this reference baseline using the best readily available geodetic surveying technique. The NGS survey involved day and night observatons with electronic distance measuring equipment, theodolites, levels and survey towers; the survey required an overall effort of approximately one man-year. The two hour MITES survey agreed with the NGS survey to 3 mm in the baseline length and better than 5 mm in all three vector components. Later in 1982 the terminal was tested in Massachusetts for baselines up to 61 km in length. The precision of the instrument (one standard deviation) was demonstrated to be approximately two parts per million. In late 1982, two dual frequency (L_1 and L_2) MITES terminals were built, and by April 1983, a total of six should be completed. With improved knowledge of the NAVSTAR satellite orbits (derived from MITES terminals at VLBI sites), a precision of 0.2 parts per million or better is anticipated with the dual frequency MITES terminals.

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